Scanning Probe Microscopy (SPM) Training Overview

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What is Scanning Probe Microscopy?

Scanning Probe Microscopy (SPM) is a catch-all phrase for numerous techniques that probe matter on the 100-μm to sub-nm length scales by sensing “near-field” interactions with a sharp physical probe. Unlike electron microscopy, which requires vacuum and (usually) special sample preparation, SPMs work in air or in liquid with minimal or no sample preparation. Unlike electron and light microscopy, the principal image does not involve lensing or the scattering intensity of electrons, photons or any other fundamental particle. Under the SPM umbrella we find Atomic Force Microscopy (AFM) and several other imaging techniques. Each SPM raster scans the surface of the sample (point-by-point, line-by-line) to create a map of the surface. The probes, techniques, and maps are diverse. The simplest, “0th-order” map is of the (3-dimensional) topography. Importantly this is a digital map of topography, so height and roughness information is obtained directly and quantitatively from the image (not from line-of-sight). Other (“1st order”) maps distinguish regions that are compositionally different from one another, contrasting electrical, mechanical, thermal, magnetic, optical, and many other properties of materials.

Which techniques will I learn?

In basic training we cover the three fundamental surface probing schemes: (i) contact mode, (ii) force curves (with optional mapping), and (iii) AC mode (often called “tapping”, though this can be a misleading term), operated in ambient air. Contact mode and force curve mapping are quasistatic techniques in that at any instant the contact is in vertical force balance as described by contact mechanics. (Models predict that contact radius increases with contact force and probe radius of curvature, and decreases with sample modulus. I.e., these variables determine resolution.) In contact mode the tip is sliding over the surface and thus friction is present, indicating dissipative (irreversible) processes during sliding. These sliding friction forces are sensitive to atomic and molecular structure (thus material properties) and can be imaged simultaneous to topography. Among other things, friction is sensitive to chemistry and thus surface contamination. Force curves (and the mapping thereof, by commercial names “pulsed force mode”, “peakforce QNM”, “force volume” and others) involve the approach and retraction of tip to sample once per measurement location, and thereby are sensitive to the (1) vertical stiffness of the tip-sample contact, and thus the mechanical properties of the sample, and (2) the stickiness of this same contact as the tip is pulled off the surface, and thus the surface chemistry. In AC/”tapping” mode the probe is instead dynamically oscillated normal to the sample at the high resonance frequency of the cantilever to which the tip is attached, such that the tip and sample intermittently interact, typically hundreds of time per measurement location. This interaction may or may not involve solid contact. In addition, a time lag (phase lag) between the driving oscillation and the actual probe-sample interaction is sensitive to energy dissipation per encounter, and thereby material properties. This phase lag can be imaged simultaneous to topography.

Which mode should I use in my research?

Contact mode is in some respects easiest and usually fastest. Thus one often chooses contact mode unless it doesn’t work well. It doesn’t work well if the probe-sample interaction is too strong, typically resulting in damaging shear forces. This is often the case on materials that are soft or weakly attached to a substrate. Moreover there can be difficulties with background signals as well as drift of the control signal (loading force) in contact mode. Force curves induce very little shear and are thus less problematic on soft and weakly bound objects; but imaging via force curves (i.e., intermittent contact) usually must proceed more slowly than in contact mode (i.e., continuous, sliding contact). Also, the force per contact is measured relative to the baseline or zero of force, such that the latter’s drift is automatically compensated. Thus force-curve mapping often requires the least “babysitting” of any mode. AC/”tapping” mode, being indeed an AC technique involving lock-in amplification, is also little affected by background signals and at least some kinds of drift. The principal difficulties in AC/”tapping” mode derive from the nonmonotonic (with distance) complexity of probe-sample interaction, and drift in the optimal parameters for driving the resonant system. A result of the resonant dynamics is that scanning is usually performed very slowly, such that a single image requires ~10 minutes, or tens of minutes, to collect. One result of interaction complexity is that it can be net attractive (sometimes meaning “non-contact”) or net repulsive (“sometimes called true tapping”). One must carefully control the regime of interaction across the entire sample surface, i.e. avoid switching between net attractive and net repulsive regimes, to avoid artifacts. But the shear interaction can be the weakest (i.e., interaction time the shortest per encounter) and thus the least problematic of all the modes; in fact non-contact imaging can allow one to image liquids (e.g., droplets, films). Moreover there are a number of “higher-order” imaging modes that are enabled within AC methods, including several electro-magnetic modes (e.g., Kelvin probe microscopy).